I. C. 7224

RECEIVED
JAN 16 1943
O. S. U. LIBRARY

November 1942

UNITED STATES
DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
R. R. SAYERS, DIRECTOR

INFORMATION CIRCULAR

DIRECTIONS FOR LABORATORY MINERAL SIZING

BY

JOHN DASHER

I. C. 7224,
November 1942.

INFORMATION CIRCULAR

UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

DIRECTIONS FOR LABORATORY MINERAL SIZING[1]

By John Dasher[2]

CONTENTS

Page
Introduction 1
Units and properties of size 2
  Dimension units 2
  Shape 2
  Other properties related to size 2
Application of sizing 3
  Maximum size 3
  Minimum size 3
  Sized fractions 4
  Products of controlled average size 4
Methods 4
  Screening 4
    Types of screens 4
    Screen scales 5
    How to screen 5
  Stokes law sizing 9
    Stokes law 9
    Elutriation 10
    Sedimentation 10
Interpretation of results 13
Conclusion 16

INTRODUCTION

The impetus given to mineral dressing and chemical engineering by the war has placed many persons without previous experience in positions where they are concerned with the size of solid materials they are testing. Many good textbooks cover this field in considerable detail but are more concerned with the "why" than with the "how." For beginners and those to whom size is not of primary concern, this brief circular has been prepared. References have been given to facilitate further study, if required. They are not necessarily the best but should be readily available. This discussion is not complete, worthwhile methods having been omitted because, in the author's opinion they are too difficult for beginners.

---

[1] The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7224."

[2] Assistant chemical engineer, Eastern Experiment Station, College Park, Md.

UNITS AND PROPERTIES OF SIZE

Dimension Units

The size of coarse particles usually is described in terms of their diameter expressed in inches. Particles of medium size are described in terms of their diameter expressed in millimeters, or in terms of the number of openings to the linear inch in a screen they will or will not pass; thus, a minus-48-mesh product is one that will pass a screen having 48 openings to the linear inch, each 0.0116 inch or 0.297 mm. square, and it does not contain particles of greater diameter than 0.3 mm. Fine particles are described in terms of their diameter expressed in microns. A micron is one one-thousandth of a millimeter. By using this system of expressing size in terms of of the English inch, the indefinite mesh, and the metric millimeter and micron, numbers with many zeros are avoided.

Shape

In the preceding paragraph, the diameter of a particle is mentioned. Only spheres have definite diameters, and very few materials have spherical particles. Many particles are irregular in shape, with approximately equal dimensions, but some are cubic, needlelike, or flaky. For coarse or medium-size particles the "diameter" or size is expressed in terms of the square (or sometimes circular) hole in a woven screen or plate through which they will or will not pass. Thus, minus-2-inch-, plus-1-inch- coal contains particles that will pass through a 2-inch- square hole but will not go through a 1-inch- square hole. For fine particles, the size, which has been determined by the falling velocity of the particles in a fluid, either gas or liquid, is expressed in terms of the diameter of a smooth sphere that will fall at the same rate. The relationship between the falling velocity and size is known as Stokes' law, which will be described later. The shape of the particles of a material is relatively independent of size and depends on the material. Therefore, for comparsion of different products of the same material, shape of particles may usually be ignored.

Other Properties Related to Size

Other properties related to size are mass or weight, volume, surface, and number per unit weight. To explain the relationship, let us take a 1-inch cube and slice it into half-inch cubes. This will require three slices and will make eight 1/2 inch cubes. Now the number of 1-inch cubes is one, which weighs one unit and has a volume of one unit, and a surface of 6 square inches. After slicing, the eight 1/2 inch cubes will have a weight of 1/8 unit each and a volume of 1/8 unit each, although, according to their dimension, they are half as big. In making each of the three slices, two new surfaces 1 inch square were formed, making a total new surface of 6 square inches and a total surface of 12 square inches. Therefore, if we halve the size of a particle, we reduce its mass and volume to one-eighth (one-eighth is the cube of one half), and we increase the number of particles eightfold, but we only double the surface. These relationships apply for other divisions of particles of irregular shape and are shown in table 1.

TABLE 1. - Relationship between dimension and other properties

Dimension	Weight and volume of 1 particle, units	Relative number per unit weight	Relative surface per unit weight
1	1	1,000	10
2	8	125	5
5	125	8	2
10	1,000	1	1
X	x^3	$1000/x^3$	10/X

APPLICATION OF SIZING

Maximum Size

Certain processes are limited in the maximum size of particles they can treat. For example, in flotation grains coarser than a certain size cannot be floated efficiently. Products for some uses are satisfactory only if they are finer than a certain size. For example, stoker coal must be small enough to enter the feeder, and glass-sand grains must be fine enough to melt within reasonable time so that unmelted grains will not spoil the glass. Therefore, it frequently is necessary to prepare a product finer than a certain size.

Minimum Size

Some processes are limited in the minimum size of particle they can treat. For example, fine particles are blown away as dust in dry tabling or remain suspended in the water and are not separated in wet tabling. Products for other uses are not satisfactory if they contain particles finer than a certain size. For example, products fed to blast, open-hearth, or other furnaces must be coarser than particles that will be blown out by the furnace draft and lost.

Sized Fractions

Many processes operate best on closely sized products; for example, tabling, jigging, and magnetic and electrostatic separation require a sized feed. For some uses, closely sized products are required; abrasives and polishing agents are ineffective if coarser or finer particles are present.

Products of Controlled Average Size

Because the reaction rate of solid particles depends on size products like cement, which contain many sizes, have to be of a controlled average size to give the setting time and strength desired. Other products that contain a wide variety of sizes such as pigments, are produced with a controlled average size because their tinting power or hiding power depends on average size and must be kept constant.

METHODS

Screening

Types of Screens

Screens are used most widely in sizing and include woven-wire screen silk bolting cloth, punched plates, and grizzlies

Silk and other textiles are used in screening food products, pigments, and a few minerals. They are relatively weak and require careful handling and light loading. Punched plates are used for coarse sizing. Their holes may be round oval, square or rectangular. They are sturdy and withstand rough service. Sizes in common use range upward from 1/4 inch. Grizzlies are parallel bars wider at the top than at the bottom. They are spaced at least 1 inch apart and are used for sizing mine-run rock or ore before coarse crushing.

However most screen sizing is done with woven-wire screens ranging in size from those with 400 meshes to the inch to screens with square openings 4 inches and larger. Although usually woven square rectangular openings are sometimes used.

For experimental purposes and for testing screen wire is mounted in sheet-metal or wooden rings. The most common type of testing screen has a brass frame 3 to 12 inches in diameter. The 8-inch-diameter screens are commonly used. When new, the brass frames nest together with screen wires approximately 2 inches apart for full-height screens and 1 inch apart for half-

Original from THE OHIO STATE UNIVERSITY

height screens. For tiny samples and for the finest sizes 3-inch-diameter screens are preferable.

Screen Scales

Since an infinite variety of screens could be made with different openings and sizes of wire. It is necessary to establish a screen scale. Unfortunately, too many groups of investigators saw this necessity.

About 1868 Rittinger proposed a series with the ratio between openings in successive screens equal to the square root of 2 or 1.414. Later, Richards proposed a series with the fourth root of 2 as a ratio. Obviously, every other screen in the Richards series would be a member of a Rittinger series. In 1910 the W. S. Tyler Co. established a standard series with the ratios between openings of successive screens approximately equal to the fourth root of 2, each screen being woven with wire of standard sizes.[3] The percentage opening in the various screens was not constant. In 1919 the Bureau of Standards proposed a United States standard series with constant percentage opening and exact fourth root of 2 ratio. Unfortunately the meshes per inch were seldom whole numbers, and the wire sizes were not standard. This division of the Bureau of Mines has continued to use screens of the Tyler series. The British Institute of Mining and Metallurgy series of 1907 was superseded in 1932 by the British Engineering Standards series, which is similar to the other series but differs when it is necessary to use British standard wire sizes. The Germans use the D.I.N. series, which has been numbered according to opening since 1934. Formerly these screens were numbered by meshes per centimeter. This series has a variable ratio between screens of 1 1/9 to 1 1/3 averaging 1.26, which is approximately equal to the cube root of 2 or the tenth root of 10. Thus, omitting the 0.090-mm. screen, we see that the first, eleventh, and twenty-first screens have openings of 6, 0.6, and 0.06mm., respectively.[4] The simple designation of mesh therefore does not define a material as to size. In table 2, the Tyler screen scale with square root of 2 ratio is given with the screens of approximately the same opening as the United States Standard and British Engineering Standard screens series. The German series is also included for comparison.

How to Screen

The passing of a particle only slightly smaller than the screen opening through that opening requires a favorable angle of approach. Therefore, complete screening is not possible in finite time. If the product that has passed through a screen in a definite time is again placed upon the screen, it will be observed that a few grains remain upon the screen. Thus, screen sizing is not absolute.

---

[3] W. S. Tyler Co. catalog 53, 1938.

[4] D.I.N. 1171, March 1934

TABLE 2. - Screen sizes (2 series)

	Tyler		United States Standard			British Engineering Standard		D.I.N.		
Opening, mm.	Mesh per inch	Wire diameter, inch	Mesh per inch	Screen No.	Wire diameter, inch	Mesh per inch	Wire diameter, inch	Screen No. (mm. opening)	Mesh per cm.	Wire diameter, mm.
26.67	-	0.148						6.0		2.5
18.85	-	.135						5.0		2.0
13.33	-	.105						4.0		1.6
9.42	-	.092						3.0		1.2
6.68	3	.070	3.03	3	0.068			2.5		1.0
4.70	4	.065	4.22	4	.050			2.0		1.0
3.33	6	.036	5.81	6	.040	5	0.068	1.5	4	1.0
2.36	8	.032	7.89	8	.0331	7	.048	1.2	5	.8
1.65	10	.035	10.72	12	.0272	10	.034	1.0	6	.65
1.17	14	.025	14.66	16	.0213	14	.024	.75	8	.5
.833	20	.0172	20.16	20	.0165	18	.022	.6	10	.4
.589	28	.0125	27.62	30	.0130	25	.0164	.5	12	.34
.417	35	.0122	38.02	40	.0098	36	.0112	.4	16	.24
.295	48	.0092	52.36	50	.0074	52	.0076	.3	20	.20
.208	65	.0072	72.46	70	.0055	72	.0056	.25	24	.17
.147	100	.0042	101.01	100	.0040	100	.004	.20	30	.13
.104	150	.0026	142.86	140	.0029	150	.0026	.150	40	.10
.074	200	.0021	200		.0021	200	.0020	.120	50	.08
.053	270	.0016	270.26		.0016			.100	60	.065
.038	400	.0010						.090	70	.055
								.075	80	.050
								.060	100	.040

The chances of a particle being able to pass through a screen opening are improved if fewer other particles hinder its motion. There is always a certain proportion of grains small enough to enter the opening but too large to pass through. These block the holes in which they are stuck. Therefore, screening is improved if the number of intermediate size grains is small. For these resons screening is most efficient when sample is small. However, a balance must be made, so that the sample will be large enough to be representative and to give fractions that can be weighed accurately on the balance available.

The motion used in dry hand-screening consists in shaking the screen (with bottom pan and, if the product is dusty, with a cover) from side to side rapidly enough to cause a good rolling motion of the particles and terminating each stroke with a bounce against the heel of the hand. This jarring is sufficient to prevent "blinding" of all but the finest screens. For such, a slight, vertical jar is helpful. Jarring may be achieved by tapping the screen bottom on the table top. If this is done violently, two things will happen: First, the screen bottom will become dented and bent, so that it will no longer fit, and second, the momentum of the mass of particles will stretch the screen wire until it is loose and distorted with many oversize holes, or it will tear the screen wire loose from the edges. Tears can be repaired by solder, but the repair concentrates the strain at the edge of the solder, so that when the procedure is repeated, the screen is even more likely to tear.

Fine products can be brushed through a screen when shaking blinds the screen, but extreme care is necessary. Application of more than the gentlest pressure due to impatience or haste will stretch the screen cloth or tear it. If the brush bristles have a diameter similar to that of the screen openings, they will enter and stick, and when they are pulled out of the screen oversize holes are created, or the bristles are pulled out of the brush and the product is contaminated. The use of a stiff-bristle brush on fine screens is objectionable also because the bristles displace the wires and create oversize holes. Fine screens are delicate and, even with good care, wear out before the frames. For all but exact testing work, wire cloth may be purchased and soldered in place in the used frames at quite a saving. For wet screening (described below), excessive strain may be removed from the fine-wire cloth by backing it with 10 mesh screen wire.

Because fine screens are so easily blinded by dust, the screening of fine, insoluble, dusty products at 100-mesh and finer is simplified by wet screening. However, some materials, such as sulfur, sulfides, and coal, are naturally water-repellent, so that they form large floccules and a scum on the water surface. For these materials, the use of wetting agents or organic liquids such as alcohol or kerosene may be necessary. For wet screening, the sample is placed upon a screen that has been wetted and placed in a pan. It is then washed with a gentle stream or fine jet of water until the water in the pan is at least 2 inches deep. Then the screen is lowered into the water on a slant to minimize the quantity of air trapped below it, leveled, and jigged with a gentle vertical motion of 1/2 to 3/4 inch amplitude, which allows the fine particles suspended in the water to flow through the screen. If the level of the screen wire is even with or below the water surface, this jigging will fill the screen with water. If the level of the screen is kept above the water more than 1/8 to 1/4 inch, the 1/2-inch-wide skirt or sleeve below the screen will not remain submerged, and jigging will produce no suction. Therefore, the level of the screen wire should be kept just above the water level. The process is continued until the material remaining on the screen is granular and offers little resistance to the downward flow of water. To test this resistance, allow the screen to fill until water is 1/2 to 1 inch deep, and shake the screen sideways. If granular, the charge will move rapidly to one side of the screen and let the water flow through. The material remaining on the screen is rinsed with clear water, washed off the screen, and dried. If the residue is small, it may be dried on the screen in an oven but not on a hot plate. The oven heat, however, increases oxidation of the copper and shortens the life of the screen.

If the wet-screened material is rescreened after drying, it will be observed that an appreciable proportion of granular particles will pass through the screen. This is due, at least in part, to the slower velocity of particles encountering the screen opening in the more viscous water. This decreases the probability of their passing.

For water-soluble materials, of course, wet screening may not be used. If the material is hygroscopic, drying in an oven and screening the material while it is still hot is advantageous.

In making a screen analysis with a series of screens, if the dry material is placed on the coarsest or top screen of a series, an appreciable quantity of dust will be observed to coat the wires of each screen in the series. To avoid this loss, the sample may be wet-screened on the finest screen first and then dried and screened on the series of screens. The amount passing the finest screen dry should be added to the quantity removed in wet screening. Where surface is to be accurately estimated, this is a necessary procedure.

A nest of several screens cannot be shaken efficiently by hand. Therefore, in hand screening the material is placed on the nest of screens and the stack is shaken for a minute, and then each screen in turn is shaken with a spare bottom pan to finish the screening. The undersize in each instance is placed on the next finer screen.

Unfortunately, some particles always are stuck in the screen after each test. They can be removed without damage to the screen if proper care is taken. A combination of methods is required. For coarse screens down to 10- or 20-mesh, fingers or fingernails will pry out the adherent particles. For finer screens, however, this method may not be used. The screens may be inverted and dropped from a height of not over 6 inches onto a sheet of paper or sample rolling cloth so that the entire periphery of the screen strikes the paper or cloth at the same time. This jar will dislodge most of the particles. If the screen is dropped from a greater height or is dropped so that one point of the rim strikes first, or if the screen is held in the hand and beaten against the table, the top rim will be dented. This will prevent the other screens from nesting above it or will make the fit so tight that the screens are difficult to stack or unstack. To remove most of the remaining particles, it may be necessary to brush the back of the screen or blow with compressed air. Brushing precautions described above should be used. Thus, simple care combined with patience will permit coarser screens to last indefinitely and the finer screens to last until the abrasion of the screened particles has worn them through.

For screen analyses, a mechanical shaker will give reproducible results down to the size where dust blinds the screen. This size depends on the fineness and nature of the product and may be as coarse as 100-mesh.

Stokes' Law Sizing

Stokes' Law

Particles falling in a vacuum have constantly increasing velocity under the acceleration of gravity, but particles falling in a fluid encounter resistance, which depends on their shape, size, density, and the viscosity and density of the fluid. This resistance increases with velocity until it equals the gravitational pull on the particle. The velocity at which this occurs is called the terminal velocity. For fine particles, this resistance is large in proportion to the pull of gravity, and they attain their terminal velocity almost immediately. The relationship between all the factors, except shape, is given for spherical particles by Stokes' law, which holds for particles finer than 200-mesh. It is written thus:

$$V = \frac{2}{9} \frac{Y^2}{K} (d - d_1) g,$$

where V = Terminal velocity, Y = radius of the sphere, d = density of the sphere, d_1 = density of fluid, g = acceleration of gravity, and K = coefficient of viscosity. All quantities are expressed in c.g.s. units. For testing use the formula may be simplified. For settling in water at room temperature (20°C.) we obtain

$$V = 545 (d - 1) D^2$$

and for air at 20°C.

$$V = 29800 \, d \, D^2,$$

where D = diameter of the particle in millimeters and V = terminal velocity in millimeters per second.

For most purposes it is possible to ignore the shape factor. If the shape factor is omitted, the diameter of a particle determined by Stokes'-law sizing methods is the diameter of a spherical particle of equal density that has the same terminal velocity.

Stokes' law does not apply to suspensions so thick that particles are not free to fall. .Suspensions with 1 percent by weight of fine solids have a detect-able error, but for most materials suspensions with 5 or even 10 percent solids are not seriously in error. Suspensions containing more than 10 percent solids have an appreciably different specific gravity and viscosity. Size analysis cannot be determined for materials that are not dispersed but that are flocculated, that is, with groups of fine particles clinging together to form a larger particle. Most minerals are easily dispersed in water but are flocculated in air. For suspensions of these, the addition of a very small quantity of tetrasodium pyrophosphate, sodium silicate, hydroxide, or carbonate is sufficient to insure dispersion. Other minerals, such as sulfur, sulfides, hydrated silicates, and coal, are difficult to wet and to disperse in water. These may be dispersed with the aid of organic dispersants made from lignin and tannin. Three things may be observed when a sample is not dispersed: (1) The settled material is not compact, (2) the liquid above the settled material is clear, or nearly so, and (3) the plot of the size distribution by the Schuhmann method, mentioned below, gives a curve that is concave downward.

Elutriation

One method of using Stoks' law for sizing is to place the material in an upward-flowing stream of fluid. This stream will carry up all particles fine enough to have a slower terminal velocity than the velocity of the upward-rising stream. Spigot and rake classifiers, thickeners, and hydroseparators work on this principle. For size analysis, elutriators operating with water and air have been developed. They are rather complex and their operation requires training and experience.

Sedimentation

If a mixture of particles and fluid is agitated until a uniform suspension is obtained, and agitation is stopped, the particles will begin to fall with a velocity depending on their size and density. The biggest, heaviest particles will settle most rapidy, and when they have all settled some finer particles that were nearer the bottom will have settled also. If, however, suspension was uniform at the beginning, the rate at which particles of each size reach the bottom is constant until those at the top have reached the bottom, at which time the rate suddenly becomes zero. Thus, by measuring the concentration of the suspension at a given depth or the rate of settling out of particles on the bottom over a period of time, we can determine the proportion of particles of each falling velocity that was present. If only one mineral is present, the proportion of each size can be determined.

For size analysis the Andreasen pipette and the various hydrometer methods are simple and rapid. They require a minimum of equipment. The Andreasen pipette consists of a graduated cylinder with a calibrated pipette that fits into a ground-glass joint at the top of the cylinder. When purchased from a chemical supply company, it is accompanied by a reprint of the article by Loomis[5], which gives directions for its use. Plotting of analyses will be facilitated if a new time schedule is chosen to give a series of sizes with a constant ratio of 2 or square root of 2. The Bouyoucos hydrometer method[6] requires a cylinder and a sensitive hydrometer of known dimensions. Calculations are simple, and the method requires no special equipment, although a special hydrometer will increase precision. Of the two methods, the pipette is more accurate, the hydrometer more simple.

The Wagner turbidimeter[7], which is standard for determining the size of portland cement, also works on the sedimentation principle. It consists of a standard light that throws a constant beam through a filter and a special cell containing the suspension onto a photoelectric cell, which operates a milliameter, from which readings are obtained. It is difficult to adapt to various materials. For cement, the sample is suspended in kerosene and dispersed with oleic acid. The surface calculated by the Wagner method is a very poor approximation of total surface, but values can be reproduced for comparison of samples.

The various sedimentation balances that have been described in the literature are subject to serious errors[8] which have been eliminated or minimized by the design of Professor Schuhmann of the Massachusetts Institute of Technology, which is illustrated in a forthcoming paper[9].

For flotation and other mineral-dressing processes, removal of particles finer than or coarser than a certain size is desirable. This can be accomplished easily and simply in the laboratory by repeated sedimentation and decantation.

After the sample is dispersed it is settled in a thin suspension for a definite time, and the material still in suspension is decanted. The settled material is again suspended, and the process is repeated as often as necessary to get as good separation as is required.

---

[5] Loomis, G. A., Grain Size of Whiteware Clays as Determined by the Andreasen Pipette: Jour. Am. Ceram Soc., vol. 21, 1938, p. 393.

[6] Bouyoucos, G. J., The Hydrometer as a New Method for Mechanical Analysis of Soils: Soil Science, vol. 23, 1927, pp. 243-253.

[7] Wagner, L. A., A Rapid Method for the Determination of the Specific Surface of Portland Cement: Proc. Am. Soc. Test. Mat., vol. 33, pt. 11, 1933, p. 553.

[8] Coutts, J. R., and Crowther, E. M., A Source of Error in Mechanical Analysis of Sediments by Continuous Weighing: Trans. Far. Soc., vol. 21, 1925, p. 379.

[9] Gaudin, A. M., Schuhmann, R., Jr., and Schlechten, A. W., Flotation Kinetics, II. - Effect of Size on Behavior of Galena Particles: Jour. Phys. Chem. (In press.)

From Stokes' law, the size of particles that will completely settle out for a given depth in a given time can be calculated easily. This size may be called the limiting size. In table 3 are given the values of the limiting size, in microns, for particles of different density for settling in water 10 inches deep for various periods. From the table it may be noted that if the time of settling is doubled, the limiting size is decreased by $\sqrt{2}$; whereas, if the settling time is four times as long, the limiting size is halved. Some particles smaller than the limiting size, which are nearer the bottom, settle out before all of the limiting-size particles have settled. Repeated resuspension of the settled material and decantation will remove more and more of the under-size in the settled material. The proportion of particles of a size that is some fraction of the limiting size remaining after any number of sedimentations and decantations can be calculated easily, knowing that the ratio V/D^2 is constant for the same material in the same suspension. Results of this calculation are given in table 4.

TABLE 3. - Limiting size for sedimentation in water 10 inches deep

Density of particle		2.0	2.5	3.0	3.5	4.0	5.0	7.0
Time, min.	Velocity, mm./sec.	mu[1]	mu	mu	mu	mu	mu	mu
1/2	8.47	124	102	88	79	72	62	51
1	4.24	88	72	62	56	51	44	36
2	2.12	62	51	44	39	36	31	25
4	1.06	44	36	31	28	25	22	18
8	.53	31	25	22	20	18	16	13
15	.282	23	19	16	14	13	11	9.3
30	.141	16	13	11	10	9.3	8.0	6.6
60	.070	11	9.2	8.0	7.2	6.4	5.7	4.6
120	.035	8.0	6.5	5.7	5.1	4.6	4.0	3.3
240	.0176	5.7	4.6	4.0	3.6	3.3	2.8	2.3

[1] mu = micron = 0.001 millimeter.

TABLE 4. - Percentage of particles finer than limiting size remaining in settled materials.

Number of sedimentations	1	2	3	4	5	6
Limiting size of particle	Amount remaining, percent					
	100	100	100	100	100	100
0.9	81	66	53	43	35	28
.8	64	41	26	17	11	7
.7	49	24	12	6	2.8	1.4
.6	36	13	4.7	1.7	.6	.2
.5	25	6.3	1.6	.4	.1	-
.4	16	2.6	.41	.1	-	-
.3	9	.81	.1	-	-	-
.2	4	.2	.01	-	-	-
.1	1	.01	.0001	-	-	-

From tables 3 and 4 it may be calculated that to reject 98 percent of the 10- micron particles we can settle and decant once with a limiting size of 67 microns and reject 91 percent of the 20-micron particles; or we can settle and decant twice at 26 microns and reject 67 percent of the 20-micron particles, or three times at 19 microns and reject none of the 20-micron particles. But the increased sharpness of the separation gained by repeated settling and decanting takes more time. For a 10-inch settling depth with quartz particles in the above example it takes 1 minute to settle once at 67 microns, or 13 minutes to settle twice at 26 microns, or 40 minutes to settle three times at 19 microns.

These calculations are in error by the proportion of the suspension, which is not decanted. Sedimentation in shallow pans is rapid, but an appreciable proportion of the suspension cannot be poured or siphoned out without loss of settled material so that rejection of fines is not as complete as the calculations show. Settling in tall columns requires much more time, but the proportion of suspension that cannot be siphoned out is quite small. Thus, a sharp separation in any depth requires a long time.

Interpretation of Results

Since the range of sizes of particles is so large, it is best to employ a geometric scale of sizes in size analysis. For careful analyses, the square root of 2 ratio is preferred, but for rough analyses a ratio of 2 is sufficient. For materials that consist of closely sized grains a fourth root of 2 ratio may be used.

In general, particulate materials may be classified into two groups. The first group includes products of crushing, grinding, pulverizing, and emulsifying. They are characterized by a wide distribution of sizes. The second group consists of materials that have a narrow range of sizes, and includes precipitates, dusts, natural sands and clays, and sized products such as abrasives.

The size-analysis results of products of the first group, which may be called comminuted materials, are susceptible of graphical analysis if plotted according to the size-distribution equations of Schuhmann 10/, Gaudin 11/, Rosin and Rammler 12/, and other similar consistant methods.

10/ Schuhmann, R., Jr., Principles of comminution. I. Size Distribution and Surface Calculations: Min. Tech., vol. 4, No. 4, p. 1. Also, Am. Inst. Min. and Met. Eng. Tech Paper 1189, 1940.

11/ Gaudin, A. M., An Investigation of Crushing Phenomena: Trans. Am. Inst. Min. and Met. Eng., vol. 73, 1926, p. 253.

12/ Rosin, R., and Rammler, E., Laws Governing Fineness of Powdered Coal: Jour. Inst. Fuel, vol. 7, 1933, pp. 29-36

Original from THE OHIO STATE UNIVERSITY

The easiest method is to plot the size analysis on semilog paper with two or more cycles, depending on the completeness of the analysis. The successive weight-percents passing any screen in a geometric series and retained on the next finer screen are plotted on the logarithmic vertical scale against the successive screen sizes spaced at equal intervals on the arithmetic horizontal scale. This is the Gaudin method. On the same sheet the total weight-percent finer than any screen may be plotted against successive sizes. This is the Schuhmann method. The relatively complete analysis of jaw-crushed quartz from the Schuhmann paper 10/, given in table 5, is plotted by the two methods in figure 1 as an example.

For ordinary crushing both of these methods will give straight, parallel lines for the finest sizes if the analysis is accurate. Therefore, if a straight line is obtained it may be extrapolated for at least half its length to determine the quantity of material of sizes finer than those measured. Determination of the slope of the two parallel lines, and for the Schuhmann line the size where it intersects with 100 percent, or for the Gaudin method the size of the peak of the curve, will permit tabular comparsion of analyses. As the scales are not the same on semilog paper, the slope must be calculated or the plot made on log paper with cumulative weight-percent finer plotted against size. Here the slope can be determined with a ruler.

If a straight line is not obtained for ordinary crushing or grinding of a rock composed of one mineral or several minerals equally hard to crush an error has been made. A few of the common causes of error detected by plotting are listed below.

Curve concave downward. - Either dust has been lost in dry crushing, or slimes in wet crushing, or the suspension for sedimentation analysis was not dispersed. This shows more readily on the Schuhmann curve.

Curve concave upward. - If clay or other finely divided or soft mineral is present in a hard rock, wet crushing will slake the clay and increase the quantity of fines produced by crushing. This also shows best on the Schuhmann plot.

Bump on the straight part of the curve. - In sedimentation this may be due to an error in weighing one fraction; or it may be due to crushing, which is too gentle to break through the grains; or, in rocks with a hard and a soft mineral, the bump will be at the grain size of the hard mineral. These bumps are more prominent on the Gaudin plot.

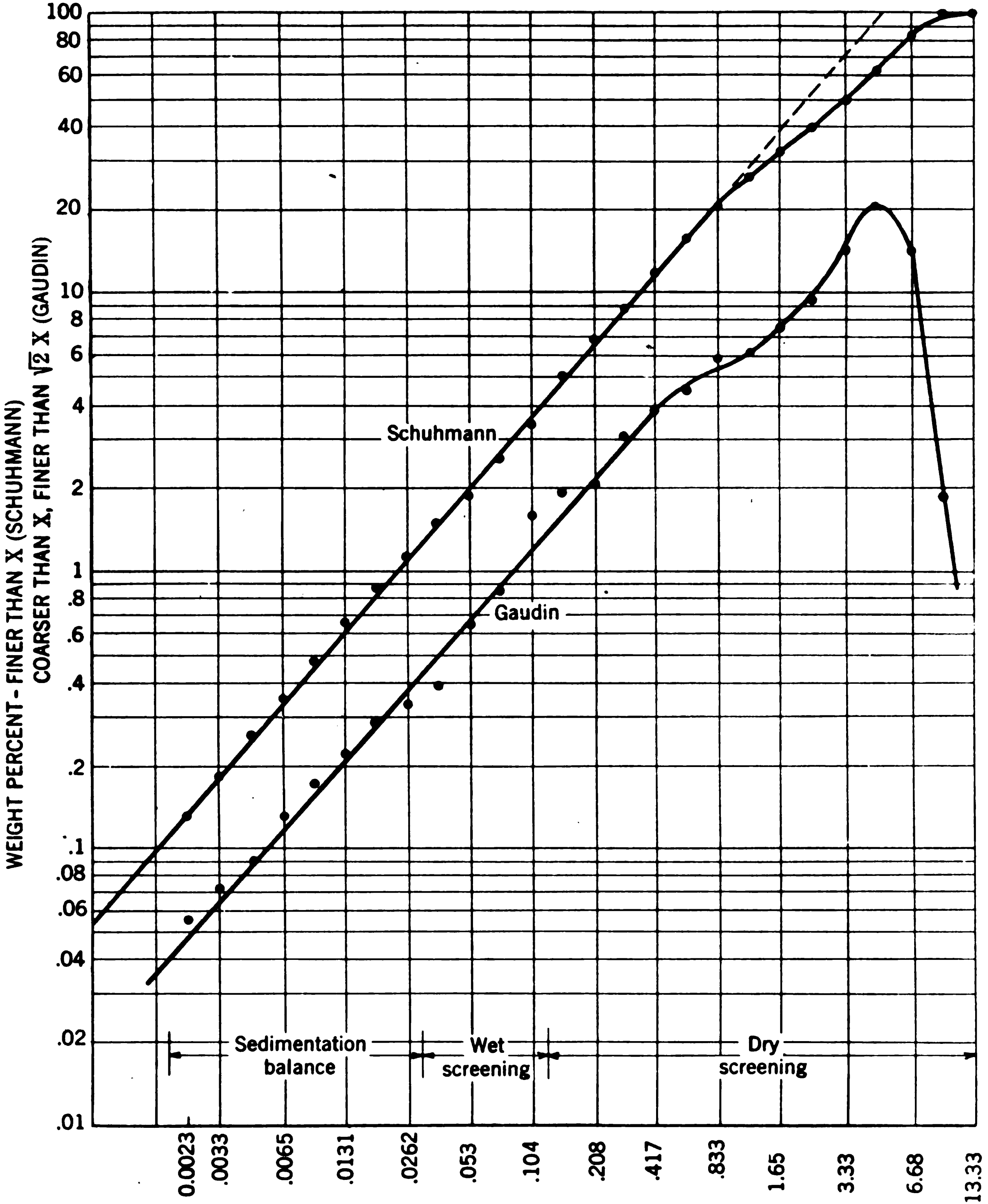

Figure 1.—Schuhmann and Gaudin methods of plotting size distribution.

TABLE 5. - Schuhmann analysis of jaw-crushed quartz

Size, Mesh	Size, mm.	Gaudin, weight percent retained on passing next coarser	Schuhmann, cumulative weight percent finer
		Tyler screens: Dry	
1/2"	13.33	0.000	100.000
3/8"	9.423	1.885	98.113
3	6.680	14.173	83.942
4	4.699	20.451	63.491
6	3.327	14.221	49.270
8	2.362	9.561	39.709
10	1.651	7.545	32.164
14	1.168	6.147	26.017
20	.833	5.833	20.184
28	.589	4.477	15.707
35	.417	3.713	11.994
48	.295	3.011	8.983
65	.208	2.049	6.934
100	.147	1.932	5.002
		Tyler screens: Wet	
150	0.104	1.613	3.389
200	.074	.848	2.541
270	.053	.645	1.896
400	.038	.394	1.502
		Sedimentation balance: Stokes' law sizes spheres	
	0.0262	0.331	1.171
	.0185	.289	.882
	.0131	.222	.660
	.0093	.175	.485
	.0065	.133	.352
	.0046	.092	.260
	.0033	.073	.187
	.0023	.056	.131
	-.0023	.131	

A bump followed or preceded by a dip in the curve. - This error is the most common and is caused by one or more successive screens having oversize openings or being blinded, or by a change from one sizing method to another; for example, determining 200-mesh dry and 270-mesh wet will almost always give a small bump in the curve followed by a dip. (See fig. 1, Gaudin plot.) Thus, if errors are small, they may be corrected by plotting; or, if they are large, plotting serves warning to repeat the analysis.

For the second class of material no general law seems to apply, but several methods of plotting will show to advantage in certain instances. Probability plotting paper is available, and the use is discussed by Austin13/ and by Hatch and Choate.14/ Lacking access to probability paper, log or semilog paper should be used so as not to crowd the points of the analyses together, as in the plots used by Loomis.15/

CONCLUSIONS

With simple, inexpensive methods, the size of particulate materials may be determined from fist-sized chunks to the colloidal range. These methods include wet and dry screening and sedimentation. No particular skill is required except carefulness, patience, and a little arithmetic. Analyses may be plotted for extrapolation or to detect errors, or to determine the constants of the material for tabular comparison.

13/ Austin, J. B., Methods of Representing the Distribution of Particle Size: Ind. Eng. Chem., vol. 11, 1939, p. 334.

14/ Hatch, T., and Choate, S., Statistical Description of Size Properties of Nonuniform Particulate Substances: Jour. Franklin Inst., vol. 207, No. 3, 1929.

15/ Work cited in footnote 5, p. 11.